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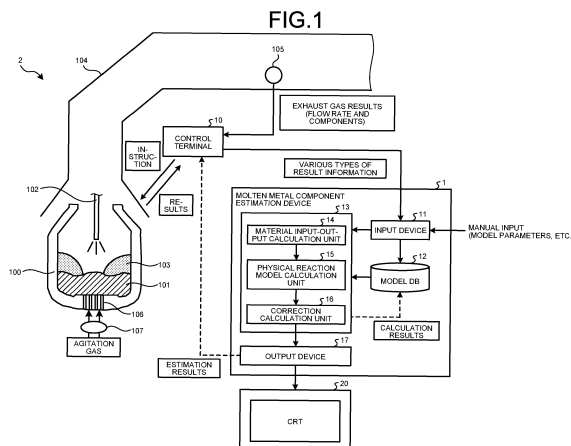
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(54) **MOLTEN METAL COMPONENT ESTIMATION DEVICE, MOLTEN METAL COMPONENT ESTIMATION METHOD, AND MOLTEN METAL PRODUCTION METHOD**

(57) A molten metal component estimation device according to the present invention includes a material input-output calculation unit that estimates an amount of carbon and an amount of oxygen charged into a refining facility and an amount of carbon and an amount of oxygen discharged from the refining facility, a physical reaction model calculation unit that estimates at least one of an amount of oxygen and an amount of carbon remaining in the refining facility, and a correction calculation unit that calculates a parameter for correcting a measurement

value of a flow rate of an exhaust gas, a parameter for correcting a measurement value of a component concentration of the exhaust gas, a parameter for correcting a calculation value of an FeO concentration in a slag, and a parameter representing the amount of carbon in the molten metal as first, second, third, and fourth correction parameters, respectively, and uses the calculated first, second, third, and fourth correction parameters to estimate component concentrations in the molten metal and the slag.



**Description**

Field

5 **[0001]** The present invention relates to a molten metal component estimation device, a molten metal component estimation method, and molten metal production method. Background

10 **[0002]** At ironworks, a component concentration and temperature of a hot metal tapped out of a blast furnace are adjusted in refining facilities, such as pretreatment facilities, converters, and secondary refining facilities. The converter process, among others, is a process of blowing oxygen into the converter to remove impurities from the molten metal and raise temperature thereof, and plays a very important role in terms of, for example, quality control of steel and rationalization of refining cost. In controlling the component concentration and the temperature of the molten metal in the converter, for example, the flow rate and speed of the top-blown oxygen, the height of a top blowing lance, the flow rate of a bottom-blown gas, and the charge amount and charge timing of auxiliary raw materials, such as lime and iron ore, are used as manipulated variables. These manipulated variables should be optimized according to the component concentrations of the molten metal and slag. However, since an intense oxidation reaction occurs in the molten metal and the temperature of the molten metal becomes very high, the component concentrations of the molten metal and slag are difficult to be measured at every moment. Therefore, methods have been proposed so far to estimate the component concentrations of the molten metal and slag in real time using in-furnace physical reaction models and measurement information in the refining facilities.

20 **[0003]** Patent Literature 1 proposes a method for sequentially estimating an FeO concentration in the slag during the blowing process by calculating a fire spot reaction and a slag-metal interface reaction using the component concentrations and the flow rate of exhaust gas discharged from the converter and operation data. However, in general, the measurement information on the exhaust gas used for estimating the component concentration of the molten metal in the converter has larger errors. For example, in general, an orifice (throttle) and a Venturi tube are installed in an exhaust gas pipe, and the flow rate value of the exhaust gas is often estimated from a pressure drop between before and after the orifice. The pressure, the temperature, and the flow rate often undergo large variations, so that the errors in the measurement values tend to be large. From such a background, Patent Literature 2 proposes a method in which a coefficient for correcting the measured value is calculated based on past results regarding the flow rate of the exhaust gas in the steel refining process, and the coefficient is further corrected based on a molten metal analysis result obtained while the blowing is being performed, and a carbon concentration of the molten metal is calculated in real time based on that information.

Citation List

35 Patent Literature

**[0004]**

40 Patent Literature 1: Japanese Patent Application Laid-open No. 2015-131999

Patent Literature 2: Japanese Patent Application Laid-open No. H09-272913

Summary

Technical Problem

45 **[0005]** However, in the method described in Patent Literature 1, when the decarburization rate and the oxidation rate of iron are calculated in the calculation of the fire spot reaction, the measured values of the exhaust gas flow rate and the component concentrations having the large errors are used as described above. Moreover, in the converter process, the model calculation values often deviate from true values due to unknown disturbances that cannot be represented by the physical model. Thus, in the method described in Patent Literature 1, it is conceivable that the estimation accuracy of the FeO concentration in the slag calculated by the fire spot and metal-slag interface reaction model often deteriorates.

50 **[0006]** Patent Literature 2 describes the method for correcting the measurement information on the exhaust gas, which corrects the flow rate of the exhaust gas based on the amount of carbon in the exhaust gas and the amount of carbon reduction in the molten metal by using component analysis information obtained by in-blow sampling of the molten metal. In the converter process, the sampling of the molten metal components is generally performed once or several times at the final stage of the blowing process.

In the above-described method, a problem is considered in which the estimation accuracy of the molten metal components deteriorates before the in-blow sampling of the molten metal is performed, causing the execution timing of the in-blow

sampling to deviate from a target value, and an operating action after the in-blow sampling is delayed.

**[0007]** The present invention has been made in view of the above problems, and an object of the present invention is to provide a molten metal component estimation device and a molten metal component estimation method that are able to estimate the component concentrations in the molten metal and the slag in an accurate and continuous manner.

It is another object of the present invention to provide a molten metal production method that is able to produce the molten metal having a desired component concentration at high yield.

#### Solution to Problem

**[0008]** To solve the problem and achieve the object, a molten metal component estimation device according to the present invention includes: an input device configured to receive: first measurement results regarding temperature and a component concentration of a molten metal before a blowing process starts or during the blowing process in a refining facility; and second measurement results regarding a flow rate and a component concentration of an exhaust gas discharged from the refining facility; a model database configured to store model expressions and parameters regarding a blowing process reaction in the refining facility; a material input-output calculation unit configured to estimate an amount of carbon and an amount of oxygen charged into the refining facility and an amount of carbon and an amount of oxygen discharged from the refining facility by performing an input-output balance calculation of carbon and oxygen based on the first measurement results, the second measurement results, the model expressions and the parameters; a physical reaction model calculation unit configured to estimate at least one of an amount of oxygen and an amount of carbon remaining in the refining facility by calculating at least one of an FeO amount in a slag and a decarburization amount in the molten metal based on the first measurement results, the model expressions and the parameters; and a correction calculation unit configured to: calculate a parameter for correcting a measurement value of the flow rate of the exhaust gas, a parameter for correcting a measurement value of the component concentration of the exhaust gas, a parameter for correcting a calculation value of the FeO concentration in the slag and a parameter representing the amount of carbon in the molten metal as first, second, third and fourth correction parameters respectively, from the second measurement results received by the input device and using the estimation results of the material input-output calculation unit and the physical reaction model calculation unit; and estimate the component concentrations in the molten metal and the slag, using the calculated first, second, third and fourth correction parameters.

**[0009]** Moreover, in the molten metal component estimation device according to the present invention, the correction calculation unit is configured to calculate the first, second, third, and fourth correction parameters so as to minimize an evaluation function having terms including: a carbon input-output error representing a difference between: an amount that is obtained by subtracting the amount of carbon discharged out of the refining facility calculated from the second measurement results, from an initial amount of carbon in the molten metal calculated from the first measurement results and an amount of carbon supplied into the refining facility by a charged auxiliary raw material; and the fourth correction parameter; an oxygen input-output error representing a difference between: a value that is obtained by subtracting an amount of oxygen consumed by carbon oxidation in the molten metal calculated from the second measurement results, carbon monoxide oxidation in the refining facility calculated from the second measurement results and impurity metal oxidation in the molten metal, from an amount of oxygen supplied to the refining facility; and an amount of oxygen consumed by iron oxidation in the molten metal calculated by the model expressions; and a primary combustion input-output error representing a difference between: a primary combustion efficiency representing a percentage of an amount of oxygen consumed by the carbon oxidation in the molten metal to an amount that is obtained by subtracting an amount of oxygen consumed by iron oxidation and impurity metals, from a top-blown oxygen feed amount and an amount of oxygen supplied by the charged auxiliary raw material; and a standard value of the primary combustion efficiency.

**[0010]** Moreover, in the molten metal component estimation device according to the present invention, the correction calculation unit is configured to calculate the first, second, third, and fourth correction parameters so as to minimize an evaluation function having terms including: a carbon input-output error representing a ratio between: an amount that is obtained by subtracting the amount of carbon discharged out of the refining facility calculated from the second measurement results, from an initial amount of carbon in the molten metal calculated from the first measurement results and an amount of carbon supplied into the refining facility by a charged auxiliary raw material; and the fourth correction parameter; an oxygen input-output error representing a ratio between: a value that is obtained by subtracting an amount of oxygen consumed by carbon oxidation in the molten metal, carbon monoxide oxidation in the refining facility and impurity metal oxidation in the molten metal calculated from the second measurement results, from an amount of oxygen supplied to the refining facility; and an amount of oxygen consumed by iron oxidation in the molten metal calculated by a physical reaction model; and a primary combustion input-output error representing a ratio between: a primary combustion efficiency representing a percentage of an amount of oxygen consumed by the carbon oxidation in the molten metal to an amount that is obtained by subtracting an amount of oxygen consumed by iron oxidation and impurity metals, from a top-blown oxygen feed amount and an amount of oxygen supplied by the charged auxiliary raw material; and a standard value of the primary combustion efficiency.

**[0011]** Moreover, in the molten metal component estimation device according to the present invention, the evaluation function is a weighted sum including a square value of the carbon input-output error, a square value of the oxygen input-output error, and a square value of the primary combustion input-output error as terms.

**[0012]** Moreover, in the molten metal component estimation device according to the present invention, a constant representing a weight of each of the terms in the evaluation function is configured to switch when a condition is satisfied, the condition being set based on at least one of molten metal component estimation information and corrected exhaust gas measurement information calculated before a calculation target time during a calculation target heat.

**[0013]** Moreover, a molten metal component estimation method according to the present invention includes: an input step of receiving: first measurement results regarding temperature and a component concentration of a molten metal before a blowing process starts or during the blowing process in a refining facility; and second measurement results regarding a flow rate and a component concentration of an exhaust gas discharged from the refining facility; a material input-output calculation step of estimating an amount of carbon and an amount of oxygen charged into the refining facility and an amount of carbon and an amount of oxygen discharged from the refining facility by performing an input-output balance calculation of carbon and oxygen based on the first measurement results, the second measurement results, and model expressions and parameters regarding a blowing process reaction in the refining facility; a physical reaction model calculation step of estimating at least one of an amount of oxygen and an amount of carbon remaining in the refining facility by calculating at least one of an FeO amount in a slag and a decarburization amount in the molten metal based on the first measurement results, the model expressions, and the parameters; and a correction calculation step of: calculating a parameter for correcting a measurement value of the flow rate of the exhaust gas, a parameter for correcting a measurement value of the component concentration of the exhaust gas, a parameter for correcting a calculation value of the FeO concentration in the slag and a parameter representing the amount of carbon in the molten metal as first, second, third, and fourth correction parameters respectively, from the second measurement results received at the input step and using the estimation results obtained at the material input-output calculation step and the physical reaction model calculation step; and estimating the component concentrations in the molten metal and the slag, using the calculated first, second, third, and fourth correction parameters.

**[0014]** Moreover, a method of producing a molten metal according to the present invention includes a step of adjusting a component concentration in a molten metal within a desired range based on the component concentration in the molten metal estimated using the molten metal component estimation method according to the present invention.

#### Advantageous Effects of Invention

**[0015]** A molten metal component estimation device and a molten metal component estimation method according to the present invention are able to estimate the component concentrations in the molten metal and the slag in an accurate and continuous manner. A molten metal production method according to the present invention is able to produce the molten metal having a desired component concentration at high yield.

#### Brief Description of Drawings

##### **[0016]**

FIG. 1 is a schematic diagram illustrating a configuration of a molten metal component estimation device as an embodiment of the present invention.

FIG. 2 is a flowchart illustrating a flow of a molten metal component estimation process as an embodiment of the present invention.

FIG. 3 is a diagram illustrating a relation between a decarburization efficiency and a degree of progress of blowing during the blowing process.

#### Description of Embodiment

**[0017]** The following describes in detail a molten metal component estimation device and operations thereof as an embodiment of the present invention with reference to the drawings.

[Configuration of molten metal component estimation device]

**[0018]** First, a configuration of the molten metal component estimation device as an embodiment of the present invention will be described with reference to FIG. 1.

**[0019]** FIG. 1 is a schematic diagram illustrating the configuration of the molten metal component estimation device as an embodiment of the present invention. As illustrated in FIG. 1, a molten metal component estimation device 1 as

an embodiment of the present invention is a device that estimates component concentrations of a molten metal 101 and a slag 103 being processed in a refining facility 2 of a steel industry. The refining facility 2 includes a converter 100, a lance 102, and a duct 104. The lance 102 is disposed above the molten metal 101 in the converter 100. High-pressure oxygen (top-blown oxygen) is ejected from a distal end of the lance 102 toward the molten metal 101 below. Impurities in the molten metal 101 are oxidized by the high-pressure oxygen, and is taken into the slag 103 (blowing process). The duct 104 for guiding exhaust gas is provided above the converter 100.

**[0020]** An exhaust gas detecting unit 105 is disposed in the duct 104. The exhaust gas detecting unit 105 detects a flow rate of the exhaust gas discharged in association with the blowing process and components (for example, CO, CO<sub>2</sub>, O<sub>2</sub>, N<sub>2</sub>, H<sub>2</sub>O, Ar) in the exhaust gas. The exhaust gas detecting unit 105 measures the flow rate of the exhaust gas in the duct 104 based on, for example, differential pressure between before and after a Venturi tube provided in the duct 104. The exhaust gas detecting unit 105 measures each of the component concentrations [%] in the exhaust gas. The flow rate and the component concentrations of the exhaust gas are measured, for example, at intervals of several seconds. Signals representing the detection results of the exhaust gas detecting unit 105 are transmitted to a control terminal 10.

**[0021]** An agitation gas (bottom-blown gas) is blown into the molten metal 101 in the converter 100 through vent holes 106 formed at the bottom of the converter 100. The agitation gas is an inert gas, such as Ar. The blown-in agitation gas agitates the molten metal 101 to promote a reaction between the high-pressure oxygen and the molten metal 101. A flow meter 107 measures the flow rate of the agitation gas blown into the converter 100. The temperature and the component concentration of the molten metal 101 are analyzed immediately before the blowing process starts and after the blowing process. The temperature and the component concentration of the molten metal 101 are measured once or a plurality of times during the blowing process, and, for example, a supply amount (oxygen feed amount) and a rate (oxygen feed rate) of the high-pressure oxygen and the flow rate of the agitation gas (agitation gas flow rate) are determined based on the measured temperature and component concentration.

**[0022]** A blowing process control system to which the molten metal component estimation device 1 is applied includes the control terminal 10, the molten metal component estimation device 1, and a display device 20 as main components. The control terminal 10 is constituted by an information processing device, such as a personal computer or a workstation, and controls the oxygen feed amount, the oxygen feed rate, and the agitation gas flow rate so as to keep the component concentration of the molten metal 101 within a desired range, and collects data of actual values of the oxygen feed amount, the oxygen feed rate, and the agitation gas flow rate.

**[0023]** The molten metal component estimation device 1 is constituted by an information processing device, such as a personal computer or a workstation. The molten metal component estimation device 1 includes an input device 11, a model database (model DB) 12, an arithmetic processing unit 13, and an output device 17.

**[0024]** The input device 11 is an input interface that receives various measurement results and result information regarding the refining facility 2. The input device 11 includes, for example, a keyboard, a mouse, a pointing device, a data receiving device, and a graphical user interface (GUI). The input device 11 externally receives, for example, the result data and parameter setting values, and writes the received information to the model DB 12, and transmits it to the arithmetic processing unit 13. The input device 11 receives the measurement results regarding the temperature and the component concentration of the molten metal 101 obtained at least either one of before the start and during the blowing process in the refining facility 2. The measurement results regarding the temperature and the component concentration are supplied to the input device 11 through, for example, manual input by an operator or reading input from a recording medium. The input device 11 receives the result information from the control terminal 10. The result information includes, for example, the information on the flow rate and the component concentrations of the exhaust gas measured by the exhaust gas detecting unit 105, the information on the oxygen feed amount and the oxygen feed rate, the information on the agitation gas flow rate, information on charge amounts of raw materials (main raw material and auxiliary raw materials), and the temperature information on the molten metal 101.

**[0025]** The model DB 12 is a storage device that stores information on model expressions for a blowing process reaction in the refining facility 2. The model DB 12 stores parameters of the model expressions as information on the model expressions for the blowing process. The model DB 12 also stores various types of information received by the input device 11 and calculation/analysis results in blowing process results calculated by the arithmetic processing unit 13.

**[0026]** The arithmetic processing unit 13 is an arithmetic processing device, such as a central processing unit (CPU), and controls overall operations of the molten metal component estimation device 1. The arithmetic processing unit 13 has functions as a material input-output calculation unit 14, a physical reaction model calculation unit 15, and a correction calculation unit 16. For example, the arithmetic processing unit 13 executes computer programs to implement the material input-output calculation unit 14, the physical reaction model calculation unit 15, and the correction calculation unit 16. The arithmetic processing unit 13 executes a computer program for the material input-output calculation unit 14 to serve as the material input-output calculation unit 14, executes a computer program for the physical reaction model calculation unit 15 to serve as the physical reaction model calculation unit 15, and executes a computer program for the correction calculation unit 16 to serve as the correction calculation unit 16. The arithmetic processing unit 13 may include dedicated

arithmetic devices or arithmetic circuits that serve as the material input-output calculation unit 14, the physical reaction model calculation unit 15, and the correction calculation unit 16.

**[0027]** The material input-output calculation unit 14 calculates a material input-output balance of components based on the operation result information, the molten metal component analysis information, the exhaust gas information, and the model information stored in the model DB 12. The material input-output balance calculation is for calculating the charge amount of each component into the converter 100 and the discharge amount of each component from the converter 100. The charge amount of each component is calculated from the charge amounts of the main raw material and the auxiliary raw materials into the converter 100, the oxygen supply from the lance 102, and an amount of air entrained from outside the converter 100.

The discharge amount of each component is calculated from the exhaust gas flow rate and the exhaust gas component concentrations.

**[0028]** The physical reaction model calculation unit 15 calculates an FeO generation/reduction reaction amount in the slag 103 and a decarburization amount in the molten metal 101 based on the model information stored in the model DB 12 and the operation result information, and estimates an amount of iron oxidation in the molten metal 101, that is, an amount of oxygen remaining as FeO in the slag 103 in the converter 100 and an amount of carbon remaining in the molten metal 101.

**[0029]** Based on the calculation results by the material input-output calculation unit 14 and the physical reaction model calculation unit 15, the correction calculation unit 16 calculates a correction parameter for the exhaust gas flow rate, correction parameters for CO and CO<sub>2</sub> concentrations in the exhaust gas, a correction parameter for an estimated FeO concentration value in the slag 103 obtained by the physical reaction model calculation unit 15, and the carbon concentration in the molten metal 101 at the time of the calculation, and uses the various calculated correction parameters to estimate the carbon concentration in the molten metal 101 and the FeO concentration in the slag 103.

**[0030]** The molten metal component estimation device 1 having such a configuration executes a molten metal component estimation process described below to estimate the component concentrations in the molten metal and the slag in an accurate and continuous manner. The following describes, with reference to a flowchart illustrated in FIG. 2, the operations of the molten metal component estimation device 1 when performing the molten metal component estimation process.

[Molten metal component estimation process]

**[0031]** FIG. 2 is the flowchart illustrating the flow of the molten metal component estimation process as an embodiment of the present invention. The flowchart illustrated in FIG. 2 starts at the time when the blowing process has started, and the molten metal component estimation process proceeds to a process at Step S1.

**[0032]** In the process at Step S1, the arithmetic processing unit 13 acquires the measurement/analysis values of the molten metal 101. The arithmetic processing unit 13 acquires the measurement/analysis results obtained by the temperature measurement and the component analysis on a sample of the molten metal 101. Thus, the process at Step S1 is completed, and the molten metal component estimation process proceeds to a process at Step S2.

**[0033]** In the process at Step S2, the arithmetic processing unit 13 acquires manipulated variable information, the exhaust gas measurement/analysis information (exhaust gas information), and the auxiliary raw material charge amount information from the control terminal 10. In a normal converter blowing operation, the manipulated variable information and the measurement/analysis information are collected at regular intervals. In the present embodiment, for the sake of simplicity, the measurement/analysis information is assumed to be collected at intervals of 2 seconds. If a large time-lag is present between the time of acquisition of the manipulated variable information and the time of acquisition of the exhaust gas measurement/analysis information, the time-lag is taken into account (the exhaust gas measurement/analysis information is accelerated by the time-lag) to create the data. If the measurement value of the exhaust gas flow rate and the analysis values of CO and CO<sub>2</sub> include large amounts of noise, the measurement value and the analysis values may be replaced with values after being subjected to smoothing processing, such as moving average calculation. Thus, the process at Step S2 is completed, and the molten metal component estimation process proceeds to a process at Step S3.

**[0034]** In the process at Step S3, the material input-output calculation unit 14 uses the information acquired in the processes at Steps S1 and S2 and the information in the model DB 12 to perform the input-output balance calculation (material input-output model calculation) of carbon and oxygen. The amount of carbon charged into the converter 100 and the amount of carbon discharged out of the converter 100 are represented as Expressions (1) and (2), respectively, given below. Hereinafter, unless otherwise noted, the symbol % represents mass%, and various flow rates are represented in basic units of flow rate.

$$C_{in} = \frac{(\rho_{pi\ g} \times W_{pi\ g} + \sum_i \rho_i^{Cscr} \times W_i^{scr} + \sum_j \rho_j^{Caux} \times W_j^{aux})}{W_{charge}} \quad (1)$$

$$C_{out} = \left( \frac{V_{CO}^{OG}}{2} + \frac{V_{CO_2}^{OG}}{2} \right) \times 12/11.2/10 \quad (2)$$

**[0035]** A charged amount of carbon  $C_{in}$  [%] denotes a value obtained by converting the sum of the amount of carbon in the main raw material and the amount of carbon in the charged auxiliary raw materials into the concentration in the molten metal 101;  $\rho_{pig}$  [%] denotes the carbon concentration in the charged hot metal;  $\rho_i^{Cscr}$  [%] denotes the carbon concentration in charged scraps (brand i);  $\rho_j^{Caux}$  [%] denotes the carbon concentration in the charged auxiliary raw material (brand j);  $W_{pig}$  [t] denotes a weight of the charged hot metal;  $W_i^{scr}$  [t] denotes a weight of the charged scraps (brand i);  $W_j^{aux}$  [t] denotes an integrated weight of the charged auxiliary raw material (brand j); and  $W_{charge}$  [t] denotes a weight of the molten metal charged into the converter 100. The carbon concentrations  $\rho_i^{Cscr}$  and  $\rho_j^{Caux}$  in the charged scrap of brand i and the charged auxiliary raw material of brand j are stored in the model DB 12, and the material input-output calculation unit 14 acquires information on the brands used in the target heats.

**[0036]** A discharged amount of carbon  $C_{out}$  [%] denotes a value obtained by converting the amount of carbon contained in the exhaust gas into the concentration in the molten metal 101, and  $V_{CO}^{OG}$  [Nm<sup>3</sup>/t] and  $V_{CO_2}^{OG}$  [Nm<sup>3</sup>/t] denote integrated flow rates of CO and CO<sub>2</sub>, respectively, in the exhaust gas until the time of calculation. An amount obtained by subtracting the discharged amount of carbon from the charged amount of carbon is the amount of carbon remaining in the converter 100, which corresponds to the carbon concentration in the molten metal 101. The charged and discharged amounts of carbon of the molten metal are assumed to be much smaller than the total amount of charge.

**[0037]** The amount of oxygen charged into the converter 100 and the amount of oxygen discharged out of the converter 100 are represented as Expressions (3) and (4), respectively, given below.

$$O_2^{in} = V_{O_2}^{blow} + \sum_j \rho_j^{Oaux} \times W_j^{aux} + \frac{21}{79} \times (V_{rem}^{OG} - V_{bot}) \quad (3)$$

$$O_2^{out} = \frac{V_{CO}^{OG}}{2} + V_{CO_2}^{OG} + V_{O_2}^{OG} \quad (4)$$

**[0038]** A charged amount of oxygen  $O_2^{in}$  [Nm<sup>3</sup>/t] denotes the sum of an integrated amount of top-blown oxygen  $V_{O_2}^{blow}$  [Nm<sup>3</sup>/t] from the lance 102, an integrated amount of oxygen in the charged auxiliary raw materials, and an integrated amount of oxygen in the air entrained from outside the converter 100 in to the converter, and  $\rho_j^{Oaux}$  [(Nm<sup>3</sup>/t)/t] denotes a converted value of an oxygen content in the charged auxiliary raw material (brand i). The oxygen content  $\rho_j^{Oaux}$  in the charged auxiliary raw material of brand j is stored in the model DB 12, and the material input-output calculation unit 14 acquires the information on the brands used in the target heats. If an exhaust gas analysis N<sub>2</sub> concentration and an exhaust gas analysis Ar concentration are not obtained in the charged oxygen amount calculation, the amount of oxygen in the entrained air may be calculated as represented by the third term of Expression (3) given above, on the assumption that an amount obtained by subtracting a bottom-blown gas amount  $V_{bot}$  [Nm<sup>3</sup>/t] from an unanalyzed exhaust gas amount  $V_{rem}^{OG}$  [Nm<sup>3</sup>/t] other than O<sub>2</sub>, CO, and CO<sub>2</sub> in the exhaust gas corresponds to N<sub>2</sub> in the entrained air.

**[0039]** A discharged amount of oxygen  $O_2^{out}$  [Nm<sup>3</sup>/t] is calculated from the amount of oxygen contained in the exhaust gas, and  $V_{O_2}^{OG}$  [Nm<sup>3</sup>/t] denotes an integrated flow rate of O<sub>2</sub> in the exhaust gas until the time of calculation. An amount obtained by subtracting the amount of discharged oxygen from the amount of charged oxygen is the amount of oxygen remaining in the converter 100, and this oxygen is used for oxidation of metal impurities such as Si, Mn, and P in the molten metal 101 and oxidation of iron. Of these oxidations, the amount of oxidation of the metal impurities is calculated by an oxidation reaction model for impurity metals stored in the model DB 12, and, for example, an oxygen amount  $V_{O_2}^{Si}$  [Nm<sup>3</sup>/t] used for Si oxidation in the molten metal 101 is represented as Expression (5) given below.

$$V_{O_2}^{Si} = \frac{\rho_{pi\ g}^{Si} \times W_{pi\ g} + \sum_i \rho_i^{Siscr} \times W_i^{scr} + \sum_j \rho_j^{Si\ aux} \times W_j^{aux}}{W_{charge}} \times \exp(-A_{Si} \times V_{O_2}^{blow}) \times 22.4/28 \times 10 \quad (5)$$

[0040]  $\rho_{pig}^{Si}$  [%] denotes a Si concentration in the charged hot metal;  $\rho_i^{Siscr}$  [%] denotes a Si concentration in the charged scraps (brand i);  $\rho_j^{Siaux}$  [%] denotes a Si concentration in the charged auxiliary raw material (brand j); and  $A_{Si}$  denotes an oxidation reaction rate constant of Si. In the same way as in Expression (5), amounts of oxygen used for oxidation of various metal impurities, such as Mn and P, in the molten metal 101 can also be calculated, and the total of the amounts is denoted as  $V_{O_2}^{met}$  [Nm<sup>3</sup>/t]. Thus, the process at Step S3 is completed, and the molten metal component estimation process proceeds to a process at Step S4.

[0041] In the process at Step S4, the physical reaction model calculation unit 15 uses the information acquired in the processes at Steps S1 and S2 and the information in the model DB 12 to calculate the FeO generation/reduction reaction amount in the slag 103 and the decarburization amount in the molten metal 101, and estimates the amount of iron oxidation in the molten metal 101, that is, the amount of oxygen remaining as FeO in the slag 103 in the converter 100 and the amount of carbon remaining in the molten metal 101. An FeO generation rate  $v_{FeO}$  [kg/min] is calculated by a physical reaction model (FeO generation/reduction reaction model) including terms representing the FeO generation/reduction reaction, and is represented as Expression (6) given below.

$$v_{FeO} = c_1 \times \frac{v_{O_2}^{blow}}{W_{charge}} \times \left(1 - \frac{R_0}{R}\right) \times \frac{1}{T_{hsp}} + c_2 \times \left(\frac{H}{D}\right)^{1.67} \times \varepsilon \times T_{bulk} \times \frac{1}{B} \quad (6)$$

[0042]  $C_1$  and  $C_2$  denote an FeO generation coefficient and an FeO reduction coefficient, respectively;  $v_{O_2}^{blow}$  [Nm<sup>3</sup>/Hr] denotes the oxygen feed rate from the lance 102;  $R$  [Nm<sup>3</sup>/s/m<sup>2</sup>] and  $R_0$  [Nm<sup>3</sup>/s/m<sup>2</sup>] denote an oxygen load and a reference oxygen load;  $T_{hsp}$  [°C] denotes fire spot temperature;  $H$  [m] denotes a bath depth of the molten metal 101;  $D$  [m] denotes a bath diameter of the molten metal 101;  $\varepsilon$  [kW/t] denotes an agitation power density of the molten metal 101 caused by the oxygen feed from the lance 102 and the bottom-blown gas;  $T_{bulk}$  [°C] denotes the temperature of the molten metal 101; and  $B$  denotes a degree of basicity of the slag 103 ( $SiO_2/CaO$  ratio in the slag component). The first term represents an FeO generation reaction rate, and the second term represents an FeO reduction reaction rate.  $C_1$  and  $C_2$  may be determined using the information acquired in the processes at Steps S1 and S2, or using the result information on the past heats stored in the model DB 12. As represented in Expression (7) given below, by integrating to accumulate the calculated FeO generation reaction rate, a cumulative FeO amount FeO [kg/t] is calculated, and the amount of oxygen remaining in the converter 100 is calculated.

$$FeO = \int v_{FeO}/60/W_{charge} dt \quad (7)$$

[0043] The decarburization amount in the molten metal 101 can be calculated using a physical model representing a decarburization efficiency during the blowing process. The decarburization efficiency  $dC/dO_2$  [10<sup>-3</sup>%/(Nm<sup>3</sup>/t)] during the blowing process represents a reduction efficiency of the carbon concentration in the molten metal 101 with respect to the oxygen feed amount from the lance 102 and the amount of oxygen supplied by the charging of the auxiliary raw materials. FIG. 3 is a diagram illustrating a relation between the decarburization efficiency and a degree of progress of blowing during the blowing process. As illustrated in FIG. 3, at an initial stage of the blowing process, the decarburization efficiency  $dC/dO_2$  increases at a gradient  $a$  with respect to a degree of progress of blowing  $T'$ , and reaches a maximum value  $(dC/dO_2)_{max}$ . Then, after the carbon concentration in the molten metal 101 reaches a critical concentration (approximately 0.4%), the decarburization efficiency  $dC/dO_2$  decreases at a gradient  $b$  with respect to the degree of progress of blowing  $T'$ . The gradients  $a$  and  $b$  of the increase and the decrease of the decarburization efficiency  $dC/dO_2$ , an intercept  $c$ , and the maximum value  $(dC/dO_2)_{max}$  can be determined using the information acquired in the processes at Steps S1 and S2, or using the result information on the past heats stored in the model DB 12. If the carbon concentration in the molten metal 101 is in a low concentration region (< approximately 0.25%), they can be calculated using a relation between the decarburization efficiency  $dC/dO_2$  and a carbon concentration  $C_s$  in the molten metal 101 represented by Expression (8) given below (decarburization model).

$$\frac{dC}{dO_2} = 107 \times \left(1 - \exp\left(\frac{m_3 - C_s \times 1000}{m_1 \times W_{slg} \cdot t \cdot m_2}\right)\right) \quad (8)$$

[0044] In the decarburization model represented by Expression (8), the decarburization efficiency  $dC/dO_2$  depends on the carbon concentration  $C_s$  [%] in the molten metal 101.  $W_{slg}$  [kg/t] denotes a weight of the slag 103, and  $m_1$ ,  $m_2$  and  $m_3$  denote constants. Thus, the process at Step S4 is completed, and the molten metal component estimation process proceeds to a process at Step S5.

**[0045]** In the process at Step S5, the correction calculation unit 16 uses the information calculated in the processes at Steps S3 and S4 and the information in the model DB 12 to calculate the correction parameter for the exhaust gas flow rate, the correction parameters for the CO and CO<sub>2</sub> concentrations in the exhaust gas, the correction parameter for the estimated FeO concentration value in the slag 103 obtained by the physical reaction model calculation, and the carbon concentration in the molten metal 101.

[Correction parameter calculation example]

**[0046]** Specifically, the correction calculation unit 16 solves a nonlinear programming problem for minimizing an evaluation function J represented by Expression (9) below or minimizing the evaluation function J represented by Expression (10) below to calculate correction parameters  $\alpha$ ,  $\beta$ ,  $\Delta FeO$ , and  $[C]$ .  $\alpha$  denotes a parameter for correcting the exhaust gas flow rate in the form of a product;  $\beta$  denotes a parameter for correcting the CO and CO<sub>2</sub> concentrations in the exhaust gas in the form of a product;  $\Delta FeO$  denotes a parameter for correcting the estimated value of FeO in the slag 103 calculated by the process at Step S4 in the form of a sum; and  $[C]$  denotes a parameter representing the carbon concentration in the molten metal 101 at the time of the calculation. In addition,  $(\ )_{temp}$  denotes an amount of change in a certain period near the time of calculation. With the introduction of the correction parameters  $\alpha$  and  $\beta$ ,  $O_2^{in}$  and  $O_2^{out}$  given by Expressions (3) and (4) are represented as Expressions (11) and (12) given below. As represented by Expression (13) given below,  $O_{2eff}$  [Nm<sup>3</sup>/t] used in Expressions (9) and (10) is an amount obtained by subtracting amounts of oxygen consumed by impurity metal combustion and iron oxidation from the oxygen feed amount from the lance 102 and the amount of oxygen supplied by the charging of the auxiliary raw materials, that is, an amount of oxygen (effective amount of oxygen) used in a reaction of oxidizing the carbon in the molten metal 101 and oxidizing the generated CO so as to generate CO<sub>2</sub>.

$$\begin{aligned}
 J = & \frac{\{C_{in} - \alpha \times \beta \times C_{out} - [C]\}^2}{\sigma_1^2} + \frac{\{(O_2^{in} - O_2^{out}) - V_{O_2}^{met} - (FeO + \Delta FeO) \times 11.2/71.85\}^2}{\sigma_2^2} \\
 & + \frac{\{\alpha \times \beta \times C_{out} \times 11.2/12 \times 10/O_{2eff} - R_{pri}\}^2}{\sigma_3^2} \\
 & + \frac{\{\alpha - \alpha_{ave}\}^2 + \{\beta - \beta_{ave}\}^2}{\sigma_4^2} + \frac{\Delta FeO^2}{\sigma_5^2} \\
 & + \frac{\{\alpha \times \beta \times (C_{out})_{temp} \times 1000 / (V_{O_2}^{blow} + \sum_j \rho_j^{Oaux} \times W_j^{aux})_{temp} - \frac{dC}{dO_2}\}^2}{\sigma_6^2}
 \end{aligned} \tag{9}$$

$$\begin{aligned}
 J = & \frac{\left\{ \frac{C_{in} - \alpha \times \beta \times C_{out}}{[C]} - 1 \right\}^2}{\sigma_1^2} + \frac{\left\{ \frac{(O_2^{in} - O_2^{out}) - V_{O_2}^{met}}{(FeO + \Delta FeO) \times 11.2/71.85} - 1 \right\}^2}{\sigma_2^2} \\
 & + \frac{\left\{ \frac{\alpha \times \beta \times C_{out} \times 11.2/12 \times 10/O_{2eff}}{R_{pri}} - 1 \right\}^2}{\sigma_3^2} + \frac{\left\{ \frac{\alpha}{\alpha_{ave}} - 1 \right\}^2 + \left\{ \frac{\beta}{\beta_{ave}} - 1 \right\}^2}{\sigma_4^2} \\
 & + \frac{\Delta FeO^2}{\sigma_5^2} \\
 & + \frac{\left\{ \frac{\alpha \times \beta \times (C_{out})_{temp} \times 1000 / (V_{O_2}^{blow} + \sum_j \rho_j^{Oaux} \times W_j^{aux})_{temp}}{\frac{dC}{dO_2}} - 1 \right\}^2}{\sigma_6^2}
 \end{aligned} \tag{10}$$

$$O_2^{in} = V_{O_2}^{blow} + \sum_j \rho_j^{Oaux} \times W_j^{aux} + \frac{21}{79} \times \left( \alpha \times V_{rem}^{OG} - V_{bot} + 2 \times \alpha \times (1 - \beta) \times \frac{V_{CO}^{OG} + V_{CO_2}^{OG}}{2} \right) \quad (11)$$

$$O_2^{out} = \alpha \times \beta \times \left( \frac{V_{CO}^{OG}}{2} + V_{CO_2}^{OG} \right) + \alpha \times V_{O_2}^{OG} \quad (12)$$

$$O_{2eff} = V_{O_2}^{blow} + \sum_j \rho_j^{Oaux} \times W_j^{aux} - V_{O_2}^{met} - (FeO + \Delta FeO) \times 11.2/71.85 - \alpha \times V_{O_2}^{OG} \quad (13)$$

**[0047]** The evaluation function J represented by Expression (9) is a weighted sum of terms that serves as an error indicator in the sixth term described below. The first term is a square value of a difference between the amount of carbon remaining in the converter 100 obtained by subtracting the discharged amount of carbon from the charged amount of carbon and [C], and a value of zero of this term indicates that the mass input-output balance of carbon is maintained in the converter 100. The second term is a square value of a difference between an amount obtained by subtracting the discharged amount of oxygen and the amount of oxygen used for the impurity metal oxidation from the charged amount of oxygen and the amount of oxygen used for the iron oxidation in the molten metal 101 calculated from the estimated value of FeO based on the physical reaction model, and a value of zero of this term indicates that the mass input-output balance of oxygen is maintained in the converter 100. The third term is a square value of a difference between a primary combustion efficiency represented by a percentage of an amount of oxygen used for oxidation (primary combustion) of the carbon in the molten metal 101 to the effective amount of oxygen and a standard value  $R_{pri}$  of the primary combustion efficiency, and a value of approximately zero of this term indicates that the primary combustion efficiency calculated based on the manipulated variables and the exhaust gas information is approximately equal to the standard value. The fourth term is square values of differences each between  $\alpha$  or  $\beta$  and a standard value  $\alpha_{ave}$  or  $\beta_{ave}$  of  $\alpha$  or  $\beta$ , and a value of approximately zero of this term indicates that  $\alpha$  and  $\beta$  are approximately equal to the standard values thereof. The fifth term is a square value of the correction parameter  $\Delta FeO$ , and is a term for preventing the calculated FeO concentration in the slag from deviating from the physical reaction model. The sixth term is a square value of a difference between the decarburization efficiency calculated from the exhaust gas information and the charged oxygen information near the time of the calculation and the decarburization efficiency based on the physical reaction model, and a value of zero of this term indicates that the measured decarburization amount is in line with the physical model.

**[0048]** In the same way, the evaluation function J represented by Expression (10) is also a weighted sum of terms that serves as an error indicator in the sixth term described below. The first term is a square value of a value obtained by subtracting one from a ratio between the amount of carbon remaining in the converter 100 obtained by subtracting the discharged amount of carbon from the charged amount of carbon and [C], and a value of zero of this term indicates that the mass input-output balance of carbon is maintained in the converter 100. The second term is a square value of a value obtained by subtracting one from a ratio between the amount obtained by subtracting the discharged amount of oxygen and the amount of oxygen used for the impurity metal oxidation from the charged amount of oxygen and the amount of oxygen used for the iron oxidation in the molten metal 101 calculated from the estimated value of FeO based on the physical reaction model, and a value of zero of this term indicates that the mass input-output balance of oxygen is maintained in the converter 100. The third term is a square value of a value obtained by subtracting one from a ratio between the primary combustion efficiency represented by the percentage of the amount of oxygen used for the oxidation (primary combustion) of the carbon in the molten metal 101 to the effective amount of oxygen and the standard value  $R_{pri}$  of the primary combustion efficiency, and a value of approximately zero of this term indicates that the primary combustion efficiency calculated based on the manipulated variables and the exhaust gas information is approximately equal to the standard value. The fourth term is square values of values each obtained by subtracting one from a ratio between  $\alpha$  or  $\beta$  and the standard value  $\alpha_{ave}$  or  $\beta_{ave}$  of  $\alpha$  or  $\beta$ , and a value of approximately zero of this term indicates that  $\alpha$  and  $\beta$  are approximately equal to the standard values thereof. The fifth term is the square value of the correction parameter  $\Delta FeO$ , and is a term for preventing the calculated FeO concentration in the slag from deviating from the physical reaction model. The sixth term is a square value of a value obtained by subtracting one from a ratio between the decarburization efficiency calculated from the exhaust gas information and the charged oxygen information near the time of the calculation and the decarburization efficiency based on the physical reaction model, and a value of zero of this term indicates that the measured decarburization amount is in line with the physical model.

[0049] In Expressions (9) and (10),  $R_{pri}$ ,  $\alpha_{ave}$ , and  $\beta_{ave}$  are determined from the results of the blowing processing mode similar to the estimation target heat among the blowing process results in the past heats stored in the model DB 12. If  $R_{pri}$  can be described by, for example, the manipulated variables and blowing process conditions, it may be used.

[0050] In the above example, weighting factors ( $\sigma_1$  to  $\sigma_6$ ) present in denominators of the respective terms of the evaluation function J are parameters set by a user. Each of the weighting factors determines a degree of influence of an amount of error in a corresponding one of the above-described terms on the valuation function J. Accordingly, the estimation accuracy can be improved by changing the weighting factor of each of the terms according to the phase of reaction in the blowing process. For example, in the low concentration region of the carbon concentration in the molten metal or in a region where the decarburization efficiency is lower, the weighting factor  $\sigma_6$  of the sixth term is changed to a smaller value in Expression (9) to increase the influence of the error in the sixth term on the evaluation function J, and thereby, can make an accurate estimation even though the carbon concentration in the molten metal is low. As described above, when a condition is satisfied that has been set based on at least one of the molten metal component estimation information and the corrected exhaust gas measurement information calculated before the calculation target time, the estimation accuracy is improved by switching the weight factor of each of the terms of the evaluation function J during the blowing process.

[0051] Various algorithms have been proposed for nonlinear programming problems for minimizing the evaluation function J under constraint conditions (refer, for example, to Non Patent Literature 1 (Hiroshi Konno and Hiroshi Yamashita, Nonlinear Programming, Union of Japanese Scientists and Engineers). The correction parameters  $\alpha$ ,  $\beta$ ,  $\Delta FeO$ , and [C] can be easily calculated using the algorithms. Thus, the process at Step S5 is completed, and the molten metal component estimation process proceeds to a process at Step S6.

[0052] In the process at Step S6, the correction calculation unit 16 uses the various correction parameters calculated in the process at Step S5 to estimate the carbon concentration in the molten metal 101 and the FeO concentration in the slag 103. Then, the arithmetic processing unit 13 transmits the estimation results of the carbon concentration in the molten metal 101 and the FeO concentration in the slag 103 estimated by the correction calculation unit 16 to the output device 17. The output device 17 outputs the estimation result of the carbon concentration in the molten metal 101 received from the arithmetic processing unit 13 to the control terminal 10 and the display device 20. The control terminal 10 adjusts the manipulated variables (for example, the oxygen feed amount and the charge amount and charge timing of the auxiliary raw materials) of the refining facility 2 based on the estimation result of the carbon concentration in the molten metal 101. The display device 20 displays the estimation results of the carbon concentration in the molten metal 101 and the FeO concentration in the slag 103. Thus, the process at Step S6 is completed, and the molten metal component estimation process proceeds to a process at Step S7.

[0053] In the process at Step S7, the arithmetic processing unit 13 determines whether the blowing process has been completed. If the result of the determination indicates that the blowing process has been completed, the arithmetic processing unit 13 ends the series of molten metal component estimation processes, and the arithmetic processing unit 13 performs a process at Step S8. If, instead, the blowing process has not ended, the arithmetic processing unit 13 returns the processing to the process at Step S2.

[0054] In the process at step S8, the arithmetic processing unit 13 stores the result data of the target heat and the calculation results of the arithmetic processing unit 13 in the model DB 12. If the measurement values of the carbon concentration in the molten metal 101 and the FeO concentration in the slag 103 at the end of the target blowing process have been obtained, these values are used to calculate various optimal correction parameters and initial parameter conditions. If error factors are present regarding elements, such as the carbon concentration analysis value  $\rho_{pig}$  in the charged hot metal and the integrated weight  $W_j^{aux}$  of the charged auxiliary raw material, that are not treated as the correction items in the present embodiment, correction parameters satisfying the components of the molten metal 101 and the component of the slag 103 at the end of the blowing process are calculated and stored in the model DB 12 in the process at Step S8 so as to be allowed to be used as initial correction parameters in the subsequent heat. Thus, the process at Step S8 is completed, and the series of molten metal component estimation processes end.

[0055] As is clear from the above description, in the molten metal component estimation process as an embodiment of the present invention, the molten metal component estimation device 1 sequentially calculates the correction parameters for correcting the measurement values of the flow rate and the component concentrations of the exhaust gas and the calculation values of the physical reaction model, based on the physical reaction model expressions, the measurement result of the component concentration of the molten metal, and the measurement results of the flow rate and the component concentrations of the exhaust gas discharged from the refining facility, so as to continuously maintain the carbon input-output balance and the oxygen input-output balance during the blowing process. As a result, the accurate estimated values of the component concentrations in the molten metal and the slag can be sequentially obtained during the blowing process.

[0056] While the embodiment to which the invention made by the present inventors is applied has been described, the present invention is not limited to the description and the drawings constituting a part of the disclosure of the present invention by way of the present embodiment. For example, in the present embodiment, the exhaust gas information has

been used as the converter measurement information that can be continuously acquired. If, for example, measurement information on the molten metal temperature is obtainable, the molten metal temperature can be continuously estimated, and, in addition, the estimation accuracy of the component concentrations of the molten metal and the slag is expected to be improved by incorporating a relational expression combined with a heat input-output balance model based on an amount of heat generated by the oxidation reaction in the converter. Thus, other embodiments, examples, operational techniques, and the like made by those skilled in the art based on the present embodiment are all included in the scope of the present invention.

Industrial Applicability

**[0057]** The present invention can provide a molten metal component estimation device and a molten metal component estimation method that are able to estimate the component concentrations in the molten metal and the slag in an accurate and continuous manner.

Reference Signs List

**[0058]**

- 1 Molten metal component estimation device
- 2 Refining facility
- 10 Control terminal
- 11 Input device
- 12 Model database (model DB)
- 13 Arithmetic processing unit
- 14 Material input-output calculation unit
- 15 Physical reaction model calculation unit
- 16 Correction calculation unit
- 17 Output device
- 20 Display device
- 100 Converter
- 101 Molten metal
- 102 Lance
- 103 Slag
- 104 Duct
- 105 Exhaust gas detecting unit
- 106 Vent holes
- 107 Flow meter

**Claims**

1. A molten metal component estimation device comprising:

an input device configured to receive:

first measurement results regarding temperature and a component concentration of a molten metal before a blowing process starts or during the blowing process in a refining facility; and  
second measurement results regarding a flow rate and a component concentration of an exhaust gas discharged from the refining facility;

a model database configured to store model expressions and parameters regarding a blowing process reaction in the refining facility;

a material input-output calculation unit configured to estimate an amount of carbon and an amount of oxygen charged into the refining facility and an amount of carbon and an amount of oxygen discharged from the refining facility by performing an input-output balance calculation of carbon and oxygen based on the first measurement results, the second measurement results, the model expressions and the parameters;

a physical reaction model calculation unit configured to estimate at least one of an amount of oxygen and an amount of carbon remaining in the refining facility by calculating at least one of an FeO amount in a slag and

a decarburization amount in the molten metal based on the first measurement results, the model expressions and the parameters; and  
a correction calculation unit configured to:

5 calculate a parameter for correcting a measurement value of the flow rate of the exhaust gas, a parameter for correcting a measurement value of the component concentration of the exhaust gas, a parameter for correcting a calculation value of the FeO concentration in the slag and a parameter representing the amount of carbon in the molten metal as first, second, third and fourth correction parameters respectively, from the second measurement results received by the input device and using the estimation results of the material  
10 input-output calculation unit and the physical reaction model calculation unit; and  
estimate the component concentrations in the molten metal and the slag, using the calculated first, second, third and fourth correction parameters.

2. The molten metal component estimation device according to claim 1, wherein the correction calculation unit is  
15 configured to calculate the first, second, third, and fourth correction parameters so as to minimize an evaluation function having terms including:

a carbon input-output error representing a difference between:

20 an amount that is obtained by subtracting the amount of carbon discharged out of the refining facility calculated from the second measurement results, from an initial amount of carbon in the molten metal calculated from the first measurement results and an amount of carbon supplied into the refining facility by a charged auxiliary raw material; and  
the fourth correction parameter;

25 an oxygen input-output error representing a difference between:

30 a value that is obtained by subtracting an amount of oxygen consumed by carbon oxidation in the molten metal calculated from the second measurement results, carbon monoxide oxidation in the refining facility calculated from the second measurement results and impurity metal oxidation in the molten metal, from an amount of oxygen supplied to the refining facility; and  
an amount of oxygen consumed by iron oxidation in the molten metal calculated by the model expressions;  
and

35 a primary combustion input-output error representing a difference between:

40 a primary combustion efficiency representing a percentage of an amount of oxygen consumed by the carbon oxidation in the molten metal to an amount that is obtained by subtracting an amount of oxygen consumed by iron oxidation and impurity metals, from a top-blown oxygen feed amount and an amount of oxygen supplied by the charged auxiliary raw material; and  
a standard value of the primary combustion efficiency.

3. The molten metal component estimation device according to claim 1, wherein the correction calculation unit is  
45 configured to calculate the first, second, third, and fourth correction parameters so as to minimize an evaluation function having terms including:

a carbon input-output error representing a ratio between:

50 an amount that is obtained by subtracting the amount of carbon discharged out of the refining facility calculated from the second measurement results, from an initial amount of carbon in the molten metal calculated from the first measurement results and an amount of carbon supplied into the refining facility by a charged auxiliary raw material; and  
the fourth correction parameter;

55 an oxygen input-output error representing a ratio between:

a value that is obtained by subtracting an amount of oxygen consumed by carbon oxidation in the molten metal, carbon monoxide oxidation in the refining facility and impurity metal oxidation in the molten metal

calculated from the second measurement results, from an amount of oxygen supplied to the refining facility;  
 and  
 an amount of oxygen consumed by iron oxidation in the molten metal calculated by a physical reaction  
 model; and

5

a primary combustion input-output error representing a ratio between:

a primary combustion efficiency representing a percentage of an amount of oxygen consumed by the carbon  
 oxidation in the molten metal to an amount that is obtained by subtracting an amount of oxygen consumed  
 by iron oxidation and impurity metals, from a top-blown oxygen feed amount and an amount of oxygen  
 supplied by the charged auxiliary raw material; and  
 a standard value of the primary combustion efficiency.

10

4. The molten metal component estimation device according to claim 2 or 3, wherein the evaluation function is a  
 weighted sum including a square value of the carbon input-output error, a square value of the oxygen input-output  
 error, and a square value of the primary combustion input-output error as terms.

15

5. The molten metal component estimation device according to claim 4, wherein a constant representing a weight of  
 each of the terms in the evaluation function is configured to switch when a condition is satisfied, the condition being  
 set based on at least one of molten metal component estimation information and corrected exhaust gas measurement  
 information calculated before a calculation target time during a calculation target heat.

20

6. A molten metal component estimation method comprising:

25

an input step of receiving:

first measurement results regarding temperature and a component concentration of a molten metal before  
 a blowing process starts or during the blowing process in a refining facility; and  
 second measurement results regarding a flow rate and a component concentration of an exhaust gas  
 discharged from the refining facility;

30

a material input-output calculation step of estimating an amount of carbon and an amount of oxygen charged  
 into the refining facility and an amount of carbon and an amount of oxygen discharged from the refining facility  
 by performing an input-output balance calculation of carbon and oxygen based on the first measurement results,  
 the second measurement results, and model expressions and parameters regarding a blowing process reaction  
 in the refining facility;

35

a physical reaction model calculation step of estimating at least one of an amount of oxygen and an amount of  
 carbon remaining in the refining facility by calculating at least one of an FeO amount in a slag and a decarbu-  
 rization amount in the molten metal based on the first measurement results, the model expressions, and the  
 parameters; and

40

a correction calculation step of:

calculating a parameter for correcting a measurement value of the flow rate of the exhaust gas, a parameter  
 for correcting a measurement value of the component concentration of the exhaust gas, a parameter for  
 correcting a calculation value of the FeO concentration in the slag and a parameter representing the amount  
 of carbon in the molten metal as first, second, third, and fourth correction parameters respectively, from  
 the second measurement results received at the input step and using the estimation results obtained at the  
 material input-output calculation step and the physical reaction model calculation step; and  
 estimating the component concentrations in the molten metal and the slag, using the calculated first, second,  
 third, and fourth correction parameters.

45

50

7. A method of producing a molten metal, the method comprising a step of adjusting a component concentration in a  
 molten metal within a desired range based on the component concentration in the molten metal estimated using  
 the molten metal component estimation method as claimed in claim 6.

55

FIG.1

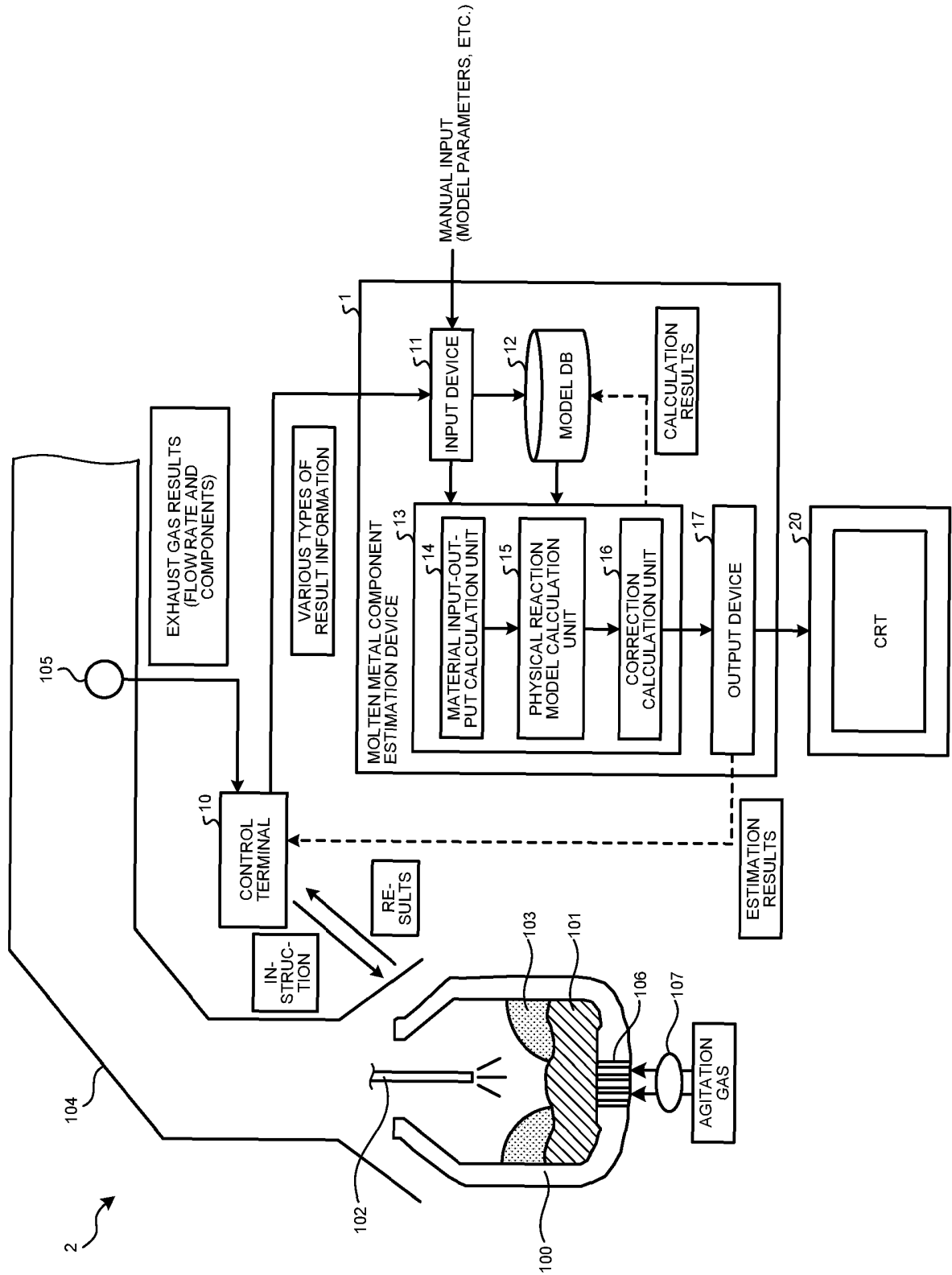


FIG.2

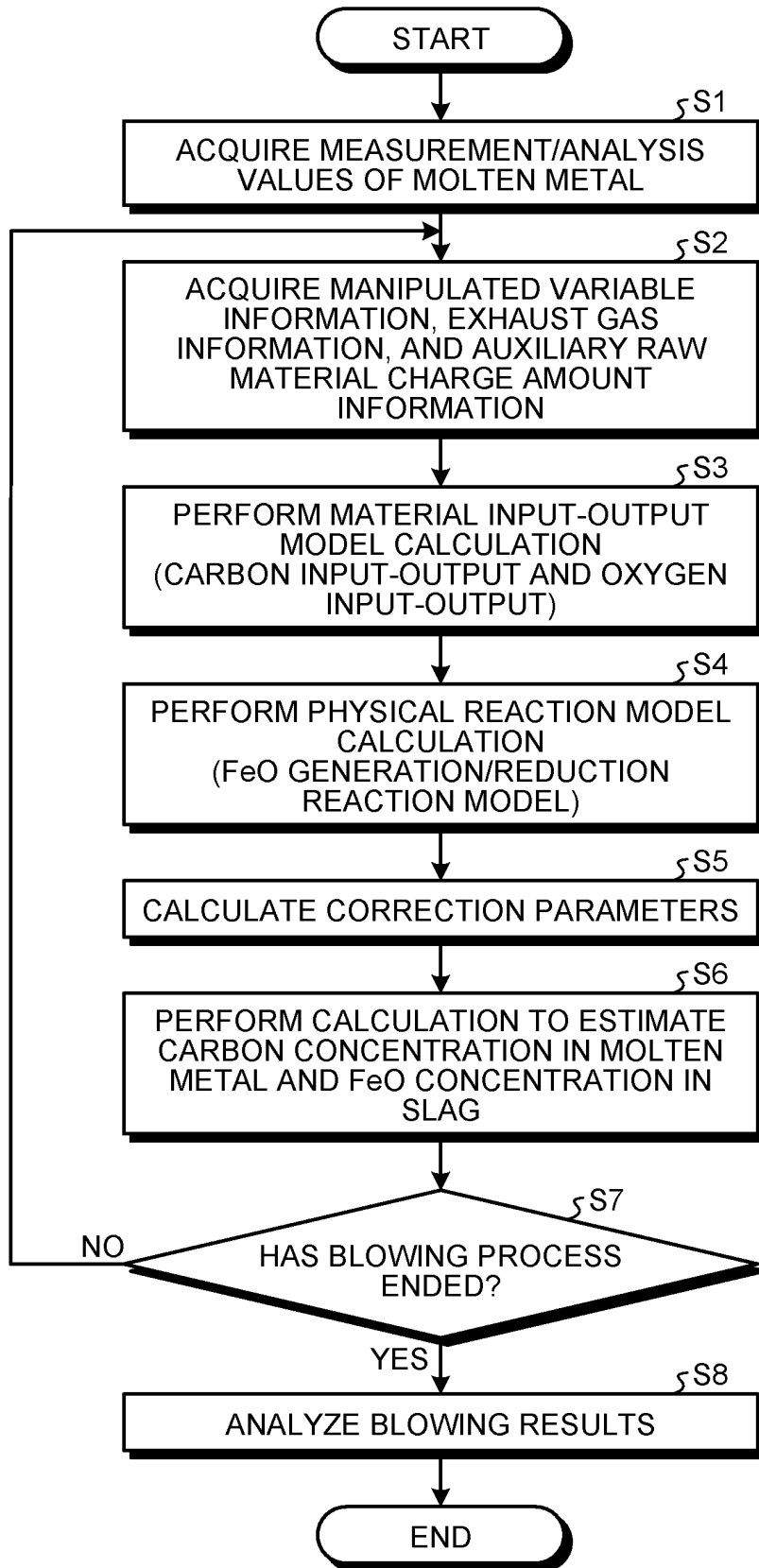
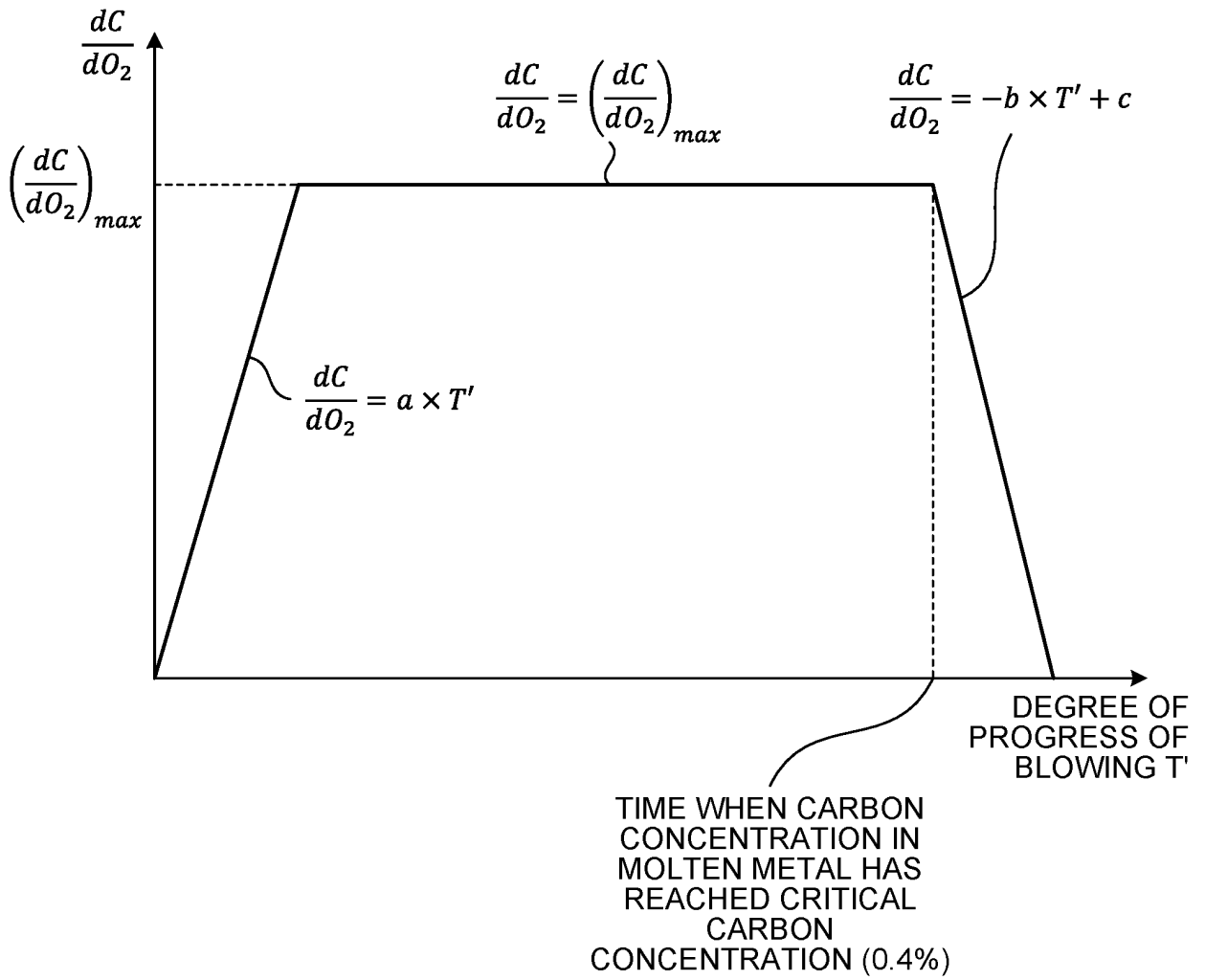


FIG.3



INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2019/009329
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5	<p>A. CLASSIFICATION OF SUBJECT MATTER</p> <p>Int.Cl. C21C5/46(2006.01) i, C21C5/28(2006.01) i, C21C7/00(2006.01) i</p> <p>According to International Patent Classification (IPC) or to both national classification and IPC</p>													
10	<p>B. FIELDS SEARCHED</p> <p>Minimum documentation searched (classification system followed by classification symbols)</p> <p>Int.Cl. C21C5/28-C21C5/50, C21C7/00-C21C7/10</p> <p>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched</p> <table border="0"> <tr> <td>Published examined utility model applications of Japan</td> <td>1922-1996</td> </tr> <tr> <td>Published unexamined utility model applications of Japan</td> <td>1971-2019</td> </tr> <tr> <td>Registered utility model specifications of Japan</td> <td>1996-2019</td> </tr> <tr> <td>Published registered utility model applications of Japan</td> <td>1994-2019</td> </tr> </table> <p>Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)</p>		Published examined utility model applications of Japan	1922-1996	Published unexamined utility model applications of Japan	1971-2019	Registered utility model specifications of Japan	1996-2019	Published registered utility model applications of Japan	1994-2019				
Published examined utility model applications of Japan	1922-1996													
Published unexamined utility model applications of Japan	1971-2019													
Registered utility model specifications of Japan	1996-2019													
Published registered utility model applications of Japan	1994-2019													
20	<p>C. DOCUMENTS CONSIDERED TO BE RELEVANT</p> <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>A</td> <td>JP 2017-89001 A (JFE STEEL CORPORATION) 25 May 2017, entire text, fig. 1-4 (Family: none)</td> <td>1-7</td> </tr> <tr> <td>A</td> <td>JP 2017-8349 A (JFE STEEL CORPORATION) 12 January 2017, entire text, fig. 1-4 (Family: none)</td> <td>1-7</td> </tr> <tr> <td>A</td> <td>WO 2015/045766 A1 (JFE STEEL CORPORATION) 02 April 2015, entire text, fig. 1-7 &amp; KR 10-2016-0040732 A &amp; CN 105593381 A</td> <td>1-7</td> </tr> </tbody> </table>		Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	A	JP 2017-89001 A (JFE STEEL CORPORATION) 25 May 2017, entire text, fig. 1-4 (Family: none)	1-7	A	JP 2017-8349 A (JFE STEEL CORPORATION) 12 January 2017, entire text, fig. 1-4 (Family: none)	1-7	A	WO 2015/045766 A1 (JFE STEEL CORPORATION) 02 April 2015, entire text, fig. 1-7 & KR 10-2016-0040732 A & CN 105593381 A	1-7
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40	<p><input type="checkbox"/> Further documents are listed in the continuation of Box C.      <input type="checkbox"/> See patent family annex.</p> <p>* Special categories of cited documents:</p> <table border="0"> <tr> <td>“A” document defining the general state of the art which is not considered to be of particular relevance</td> <td>“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>“E” earlier application or patent but published on or after the international filing date</td> <td>“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</td> </tr> <tr> <td>“O” document referring to an oral disclosure, use, exhibition or other means</td> <td>“&amp;” document member of the same patent family</td> </tr> <tr> <td>“P” document published prior to the international filing date but later than the priority date claimed</td> <td></td> </tr> </table>		“A” document defining the general state of the art which is not considered to be of particular relevance	“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	“E” earlier application or patent but published on or after the international filing date	“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	“O” document referring to an oral disclosure, use, exhibition or other means	“&” document member of the same patent family	“P” document published prior to the international filing date but later than the priority date claimed			
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50	<p>Date of the actual completion of the international search</p> <p>14 May 2019 (14.05.2019)</p>	<p>Date of mailing of the international search report</p> <p>28 May 2019 (28.05.2019)</p>												
55	<p>Name and mailing address of the ISA/ Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan</p>	<p>Authorized officer</p> <p>Telephone No.</p>												

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